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Review

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Impacts of the 20th January 2005 solar proton event on the ozone concentration of Indian cities

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Abstract The ozone data obtained from Nimbus-7 and Earth probe Total Ozone Mapping Spectrometer (TOMS) has been used to study the impact of coronal mass ejection (CME) on the columnar ozone concentration in India. A comparison of columnar ozone values for different solar proton events (SPE) observed at Srinagar indicates that although the 20th Jan., 2005 SPE was the most intense in the last 15 years, the ozone depletion was found to be maximum in the 23rd March, 1991 event followed by 20th Jan., 2005, 4th Nov., 2001, 19th Oct., 1989 and 28th Oct., 2003 events. A comparison between the ozone levels observed in different Indian cities for a few days after the 20th Jan., 2005 SPE indicates that the ozone values were found to decrease sharply at higher latitudes compared to places located in the tropics. The ozone values measured by TOMS, Dobson Spectrometer and AURA Ozone Monitoring Instrument (OMI) were found to decrease for a short period from 20th January to 25th January after which the ozone levels started recovering to normal values. The vertical ozone profiles obtained from Microwave Limb Sounder for New Delhi, indicate that the ozone-mixing ratio in the 3.0 to 10.0 hP_a pressure range decreased consistently from 21st Jan., 2005 to 25th Jan., 2005 and thereafter, recovered by the 31st January, 2005.

Keywords Ozone depletion, solar proton event (SPE), coronal mass ejection (CME), HO_x, NO_x

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1. Introduction

Large solar storms rain electrically charged particles called protons down on Earth's atmosphere, which break up molecules of gases like nitrogen and water vapour, and once freed, these atoms react with ozone molecules and deplete the upper-level ozone for weeks to months thereafter[1]. The enhanced ionization affects not only the ionosphere but also some of the minor neutral constituents between upper stratosphere and the mesopause. Odd hydrogen (HO_x = H+OH+HO_2) and odd nitrogen species (NO_x = N+NO+NO_2) are produced by proton and secondary electron impact on N_2. When nitrogen gas molecules split apart, they create molecules, called nitrogen oxides, which last several weeks to months depending on where they end up in the atmosphere. Once formed, the nitrogen oxides react quickly with ozone and reduce its amounts. When atmospheric winds blow them down into the middle stratosphere, they can stay there for months, and continue to keep ozone at a reduced level. Protons similarly affect water vapour molecules by breaking them up into forms where they react with ozone. However, these molecules, called hydrogen oxides, last only during the time period of the solar proton event. These short-term effects of hydrogen oxides can destroy up to 70 percent of the ozone in the middle mesosphere. At the same time, long-term ozone loss caused by nitrogen oxides destroys a maximum of about nine percent of the ozone in the upper stratosphere[2]. Jackman *et al* [3] used their two-dimensional chemistry and transport atmospheric model to simulate the influence of solar proton events (SPEs) over the 1965 to 1995 time period. They found that extremely large particle events with huge fluxes of very high-energy protons occurred in August 1972 and October 1989 and caused large increases in long-lived NO_x constituents, which affected ozone for several months to years past the events. The SPE-produced NO_x constituents in the upper stratosphere caused direct ozone losses. They predicted a seasonal dependence for the impact on polar ozone, with larger (smaller) decreases predicted for SPEs occurring in the fall or winter (spring or summer). Verronen *et al* [4] studied ozone depletion

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in the northern hemisphere middle atmosphere due to the October-November, 2003 solar proton events. They observed an increase in NO_2 concentration by several hundred percent and a simultaneous decrease in ozone by tens of percent at altitudes above 36 km. The maximum effect, a 60% reduction in ozone at 42 km, was observed in the end of November, a month after the solar proton event. Afterwards, a partial recovery of ozone occurred towards the end of the year. Jackman *et al* [5] studied the impact of solar storms in October–November, 2003 on the middle atmospheric polar cap regions.

They observed that the highly energetic protons associated with the SPEs produced ionizations, excitations, dissociations, and dissociative ionizations of the background constituents, which led to the production of odd hydrogen (HO_x) and odd nitrogen (NO_y) which was observed by the UARS / HALOE instrument to increase over 20 ppbv throughout the southern hemisphere polar lower mesosphere. The NOAA 16 SBUV/2 instrument measured a short-term ozone depletion of 40% in the southern hemisphere polar lower mesosphere, which was probably due to an increase in HO_x. SBUV / 2 observations showed ozone depletion of about 5–8% in the southern polar upper stratosphere lasting for days beyond the event, which was attributed to enhancement in NO_y. The Goddard Space Flight Center two-dimensional model predicted long-term northern hemisphere polar total ozone decrease greater than 0.5% to last for over 8 months past the events. They concluded that although the production of NO_y constituents is the same in both hemispheres, the NO_y constituents have a much larger impact in the northern than the southern polar latitudes because of the seasonal differences between the two hemispheres. Between January 15th and 19th, 2005, four powerful solar flares erupted from sunspot 720. Then on January 20, the fifth explosion produced a coronal mass ejection (CME) that achieved velocities incomparably greater than anything astronomers had seen before. While it generally takes more than 24 hours for the charged particles of a solar outburst to reach the earth, this one was a profound exception. Just thirty minutes after the explosion, Earth (some 96 million miles away from the sun) was immersed in what NASA scientists called the most intense proton storm in decades. The solar energetic particle event of January 20, 2005 has been the most intense in 15 years, with a greater than100 MeV proton intensity comparable to that of the October, 1989 event [6-8] .This event was also the largest ground-level neutron monitor event in many years, providing evidence that protons were accelerated to energies of several GeV [9].

2. Data and analysis

The ozone data obtained from Nimbus-7 and Earth probe Total Ozone Mapping Spectrometer (TOMS) for the years 1989 -2005 has been used to study the impact of CME on the columnar ozone in India. TOMS is a source of high-resolution global information about the total ozone content of the atmosphere. It measures the ultraviolet sunlight back scattered from the clouds or the ground to measure the total ozone amount.

The variation in columnar ozone values determined from satellite-based TOMS data is supported with ground-based ozone data measured with Dobson Spectrometer at Delhi. The Dobson Spectrometer is widely used for measuring the total columnar ozone content in the atmosphere. It uses the fact that since ozone has a series of bands in the ultraviolet absorption spectrum, by measuring the solar ultraviolet radiation transmitted to the surface at several pairs of wavelength's, one close to an absorption maxima, and one away from it, the total columnar ozone content can be calculated.

The total columnar ozone values obtained from AURA Ozone Monitoring Instrument (OMI) and vertical ozone profiles measured by Microwave Limb Sounder (MLS) have been obtained through GES-DISC Interactive Online Visualization and Analysis Infrastructure (Giovanni).

Ozone Monitoring Instrument (OMI) monitors the recovery of the stratospheric ozone layer. It measures both ultraviolet and visible radiation and provides daily high-resolution global maps and profiles of ozone. MLS is a microwave sensor, which is able to measure trace gases inside the clouds. It focuses on the upper troposphere and stratosphere, measuring microwave radiation emitted by ozone, chlorine compounds and many other traces gases.

3. Results and discussion

A comparison of columnar ozone obtained from Nimbus -7 and Earth- probe TOMS for three to six consecutive days after different SPE events observed at Srinagar (34 N, 74.8 E) is shown in Figure 1.It is observed that although the 20th Jan., 2005 SPE

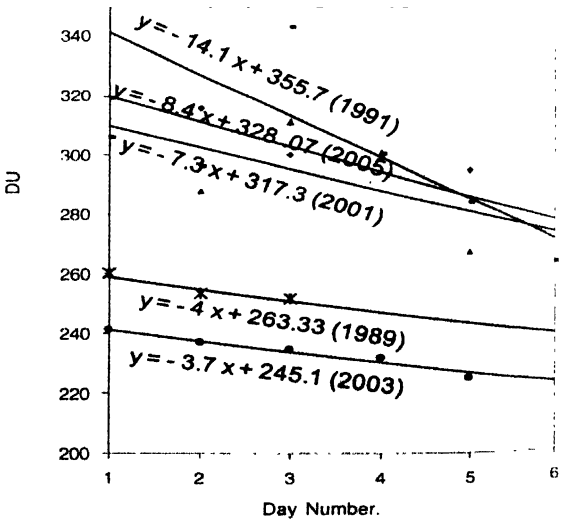

Figure 1. Comparison of columnar ozone for three to six consecutive days in different SPE's observed at Srinagar.

was the most intense in the last 15 years, with >100 MeV proton intensity comparable to that of the October, 1989 event, the ozone depletion was found to be maximum in the 23rd March, 1991 event followed by 20th Jan., 2005, 4th Nov .,2001, 19th Oct., 1989 and 28th Oct., 2003 events. This may be because a volcanic eruption Hekla was reported in Iceland on the 17th January, 1991. The eruption cloud was north of the terminator in the polar night region for the first few days of atmospheric residence, and then it moved south across Russia and was detected by TOMS near the Black Sea. Volcanic eruptions are potential sources of SO_2, HCL, BrO and H_2O in the lower stratosphere. SO_2 emitted from the volcanoes gets converted into H_2SO_4 and condenses into small aerosol particles in the stratosphere. These aerosol clouds provide an increased scope for heterophase chemistry and enhanced ozone depletion. Volcanic particles generally take two or three years to settle out of the stratosphere. The large depletion in ozone levels observed after the 23rd March, 1991 SPE may be due to the combined effects of the Hekla volcanic eruption in Iceland and SPE.

A comparison of ozone values for different Indian cities after the 20th January, 2005 SPE indicated that the observed decrease in ozone values was found to vary with latitude. The ozone values were found to decrease sharply at places situated at higher latitudes like Srinagar and Delhi (First solid line and first dotted line respectively in Figure 2) compared to places located in the tropics like Rajkot,Trivandrum and Hyderabad (Second, third and fourth solid lines respectively in Figure 2). This is because solar storms lead to ejection of large amount of high-energy protons that can penetrate the Earth's magnetic field near the poles. These protons penetrate into the atmosphere, (40 to 80 km layer) causing ionization of air molecules. As the ionized particles recombine, they produce nitrogen and hydrogen oxides, which can affect ozone through the NO_x and HO_x catalytic cycles.

The decrease in ozone values using TOMS data was observed for a short period from 20th January to 25th January after which the ozone levels started recovering to normal values (Figure 2). Similar results were observed for ground based columnar ozone values measured with Dobson spectrometer at Delhi from 19th January to 28th January (Figure 3). These effects are short-lived because the hydrogen oxides which cause the primary ozone loss recombine within hours.

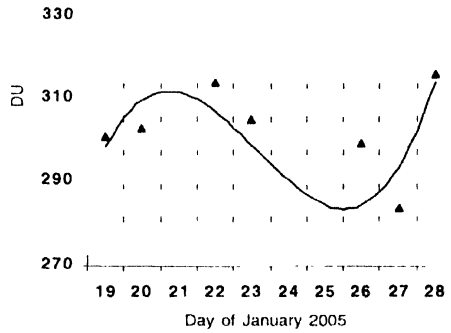

Figure 3. Columnar ozone recorded at Delhi using Dobson Spectrometer from 19th to 28th January, 2005

An examination of total columnar ozone values obtained from AURA Ozone Monitoring Instrument (OMI) indicates that the ozone levels in northern and central India on the 24th/25th January, 2005 were lower by about 20 to 30 Dobson units compared to 20th /21st January, 2005.The ozone levels thereafter started recovering gradually around the 30th /31st January, 2005 (Figure 4).The recovery in ozone levels was observed to be faster in northern India, compared to central India.

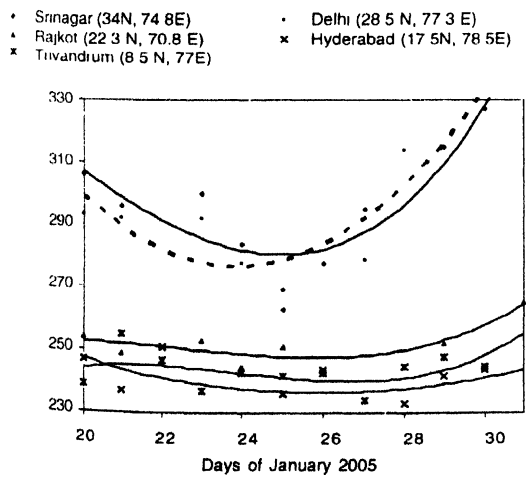

Figure 2. Columnar ozone measured by TOMS over different Indian cities from 20th to 31st January, 2005.

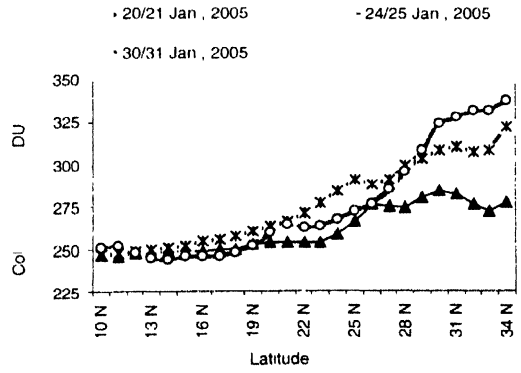

Figure 4. Columnar ozone values for Indian latitudes obtained from AURA Ozone Monitoring Instrument for Jan., 2005.

NO_x is the most important destroyer of ozone in the 25-45 km altitude region. In the NO_x cycle, the radical that destroys ozone is NO.

The catalytic cycle is:

$$NO + O_3 \rightarrow NO_2 + O_2.$$
$$NO_2 + O \rightarrow NO + O_2.$$
$$NET: O_3 + O \rightarrow 2O_2.$$

This process is catalytic since NO initiates ozone destruction process, but is regenerated, so that no net consumption of NO occurs. In the hydrogen cycle, the radical which destroys ozone, is the Hydroxyl radical OH.

The catalytic reaction is:

$$OH + O_3 \rightarrow HO_2 + O_2$$
$$HO_2 + O \rightarrow OH + O_2.$$
$$NET: O_3 + O \rightarrow 2O_2$$

Other members of the HO_X family which destroy ozone are H and HO_2

$$H + O_3 \rightarrow OH + O_2.$$
$$OH + O \rightarrow H + O_2.$$
$$NET: O_3 + O \rightarrow 2O_2.$$

$$HO_2 + O \rightarrow OH + O_2.$$
$$OH + O_3 \rightarrow HO_2 + O_2.$$
$$NET: O_3 + O \rightarrow 2O_2$$

An examination of vertical ozone profiles obtained from Microwave Limb Sounder from 20th – 31st Jan., 2005 for New Delhi (Figure 5) indicates that the ozone mixing ratio in ppmv in the 7.0 to 3.0 hPa pressure range (approximately 32 to 40 km altitude range) is found to decrease consistently from 21st Jan., 2005 to 25th Jan., 2005. The ozone levels are found to recover by the 31st of January, 2005. The SPE-produced NO_x constituents in the upper stratosphere cause direct ozone losses. However, interference of the NO_x constituents with the halogen loss cycles for ozone destruction might have actually led to some ozone production in the 15 to 25 hPa pressure range (approximately 22 to29 km altitude range) on the 25th and 26th January. Jackman et al [3] observed similar results in their two-dimensional chemistry and transport atmospheric model. Since the solar proton event is found to deplete very little total ozone for a short period in India, its negative impacts on humans will be very little

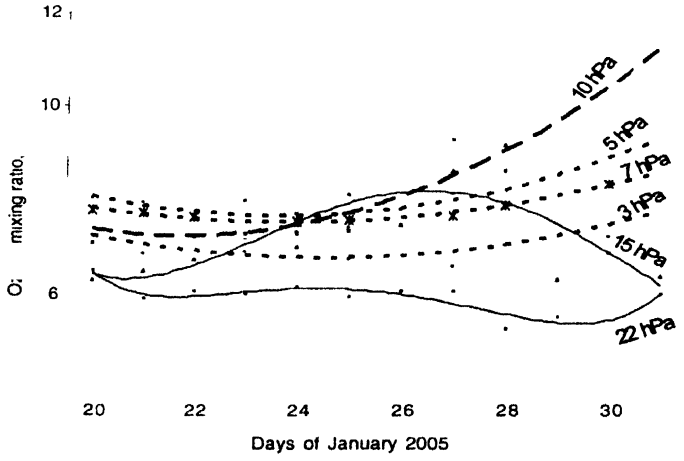

Figure 5. Vertical ozone profiles for New Delhi obtained from Microwave Limb Sounder from 20th - 31st Jan., 2005 .

4. Conclusions

Ozone data obtained from Nimbus- 7 and Earth- probe TOMS for the years 1989 - 2005 has been used to study the impact of CME on the columnar ozone in India. A comparison of columnar ozone for different SPE observed at Srinagar indicates that although the 20th Jan., 2005 SPE event was the most intense in the last 15 years, the ozone depletion was found to be maximum in the 23rd March, 1991 event followed by 20th Jan., 2005, 4th Nov., 2001, 19th Oct., 1989 and 28th Oct., 2003 events. The observed decrease in ozone values during the SPE was found to vary with latitude. The ozone values were found to decrease sharply at higher latitudes compared to places located in the tropics. The decrease in ozone values was observed for a short period of about 5 days, after which the ozone levels started recovering to normal values.

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